

Table 4-2. Annual inventories (grams) of nonradionuclide contaminants of potential concern buried in the Subsurface Disposal Area from 1952 to 1999.

| Contaminant | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 0.00E+00 | 0.00E+00 | 4.99E+04 | 2.06E+05 | 4.05E+05 | 5.81E+05 | 1.33E+06 | 1.46E+06 |
| Methylene chloride | 0.00E+00 | 0.00E+00 | 2.11E+04 | 1.06E+05 | 2.13E+05 | 3.08E+05 | 7.16E+05 | 7.86E+05 |
| Tetrachloro-ethylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Nitrates | 0.00E+00 | 0.00E+00 | 2.92E+06 | 2.92E+06 | 2.92E+06 | 2.92E+06 | 2.92E+06 | 2.92E+06 |

| Contaminant | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 1.73E+06 | 1.58E+06 | 2.06E+06 | 2.50E+06 | 2.15E+06 | 3.08E+06 | 1.76E+08 | 1.74E+08 |
| Methylene chloride | 9.30E+05 | 8.51E+05 | 1.11E+06 | 1.35E+06 | 1.16E+06 | 1.66E+06 | 2.03E+06 | 7.80E+05 |
| Tetrachloro-ethylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.12E+07 | 2.12E+07 |
| Nitrates | 2.92E+06 | 2.94E+06 | 2.94E+06 | 2.94E+06 | 3.49E+06 | 2.88E+06 | 2.88E+06 | 3.45E+07 |

| Contaminant | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 1.73E+08 | 1.74E+08 | 1.06E+08 | 8.61E+00 | 8.61E+00 | 8.61E+00 | 8.61E+00 | 8.61E+00 |
| Methylene chloride | 3.37E+05 | 9.80E+05 | 7.60E+05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Tetrachloro-ethylene | 2.12E+07 | 2.12E+07 | 1.30E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Nitrates | 3.45E+07 | 3.45E+07 | 2.21E+07 | 2.18E+07 | 5.35E+07 | 3.26E+07 | 3.26E+07 | 3.26E+07 |

| Contaminant | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 8.61E+00 | 8.61E+00 | 8.61E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Methylene chloride | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Tetrachloro-ethylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Nitrates | 3.26E+07 | 3.26E+07 | 3.26E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| Contaminant | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Methylene chloride | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Tetrachloro-ethylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Nitrates | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| Contaminant | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | Total |
|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Carbon tetrachloride | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.21E+08 |
| Methylene chloride | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.41E+07 |
| Tetrachloro-ethylene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.78E+07 |
| Nitrates | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.35E+08 |

4.1.2 Ingrowth

Waste in the SDA contributes radionuclides to the source term inventory either directly through disposals (see Table 4-1) or over time through ingrowth. Ingrowth is incremental accumulation of daughter products generated by decay of the parent. Of the 25 radionuclides listed in Table 4-1, 11 of them are members of decay chains: Am-241, Ac-227, Np-237, Pa-231, Pb-210, Ra-226, U-233, U-234, U-235, U-236, and U-238. Three decay chain series, named after the initiating nuclide, occur naturally: the thorium, uranium, and actinium series. A fourth decay chain, the neptunium series, has not occurred naturally since the creation of the cosmos.

Decay chain members for the four series are listed in the sequences they occur in Table 4-3 for the thorium series, Table 4-4 for the neptunium series, Table 4-5 for the uranium series, and Table 4-6 for the actinium series, as documented by Shleien (1992). Two nuclides in the same row of the table indicate that both can emanate from the parent nuclide listed above. Typically, the first decay product is common and the second is rare. The exception is the Po-211 and Tl-207 pair near the termination of the actinium series. Half-lives also are listed. The COPCs identified in Becker et al. (1998) and discussed in this report are shaded green in Tables 4-3 through 4-6. The inventories of these COPCs are significantly affected over time as the parent nuclides decay and daughters accumulate. For some COPCs, such as Np-237, the inventory from ingrowth exceeds the inventory from disposal, while other COPCs such as Am-241 generate risk through radioactive decay. Throughout Section 4, the contributions to COPCs from parents via ingrowth are identified in the waste stream tables for the affected nuclides. The ingrowth amounts identified in the tables were calculated by assuming that the contributing parent isotope completely decays away and the daughter COPC only accumulates.

Table 4-3. Decay chain for the thorium decay series, including anthropic predecessors from weapons manufacturing or reactor operations.

| Anthropic Predecessor (Half-Life) | | Decay Chain Series Isotope (Half-Life) |
|--------------------------------------|----------------------------|---|
| Pu-240 (6560 years) | U-236 (2.342E+07 years) | Th-232 (1.4E+ 10 years) |
| | | Ra-228 (5.75 years) |
| | | Ac-228 (6.13 hours) |
| | | Th-228 (1.913 years) |
| | | Ra-224 (3.66 days) |
| | | Rn-220 (56.6 seconds) |
| | | Po-216 (0.15 seconds) |
| | | Pb-212 (10.64 hours) |
| | | Bi-212 (1.009 hours) |
| | | Po-212 (305 nanoseconds) |
| | | Tl-208 (3.07 minutes) |
| | | Pb-208 Stable |

Table 4-4. Decay chain for the neptunium series

| Nuclide (Half-Life) | |
|------------------------------|-------------------------|
| Pu-241 (14.4 years) | |
| Am-241 (432.2 years) | U-237 (6.75 days) |
| Np-237 (2.14E+06 years) | |
| Pa-233 (27.0 days) | |
| U-233 (1.59E+05 years) | |
| Th-229 (7.34E+03 years) | |
| Ra-225 (14.8 days) | |
| Ac-225 (10.0 days) | |
| Fr-221 (4.8 minutes) | |
| At-217 (0.03 seconds) | |
| Bi-213 (45.7 minutes) | |
| Po-213 (4.2 microseconds) | Tl-209 (2.2 minutes) |
| Pb-209 (3.25 hours) | |
| Bi-209 Stable | |

Table 4-5. Decay chain for the uranium series and anthropic predecessors from weapons manufacturing or reactor operations.

| Anthropic Predecessor (Half-Life) | Decay Chain Series Isotope (Half-Life') |
|--------------------------------------|--|
| Pu-238 (87.7 years) | U-238 (4.47E+09 years) |
| | Th-234 (24.1 days) |
| | Pa-234m (1.17 minutes) |
| | Pa-234 (6.7 hours) |
| | U-234 (2.45E+05 years) |
| | Th-230 7.7E+04 years |
| | Ra-226 (1,600years) |
| | Rn-222 (3.823 days) |
| | Po-218 (3.05 minutes) |
| | Pb-214 (26.8 minutes) |
| | Bi-214 (19.9 minutes) |
| | Po-214 (164 microseconds) |
| | Tl-210 (1.3 minutes) |
| | Pb-210 (22.3 years) |
| | Bi-210 (5.01 days) |
| | Po-210 (138.4 days) |
| | Tl-206 (4.20 minutes) |
| | Pb-206 Stable |

Table 4-6. Decay chain for the actinium series, including predecessors from weapons production or reactor operations.

| Anthropic Predecessor (Half-Life) | | | Decay Chain Series Isotope (Half-Life) |
|--------------------------------------|------------------------|----------------------------|---|
| Am-243 (7.37E+03 years) | Np-239 (2.355 days) | Pu-239 (2.41E+04 years) | U-235 (7.04E+08 years) |
| | | | Th-231 (25.5 hours) |
| | | | Pa-231 (3.276E+04 years) |
| | | | Ac-227 (21.44 years) |
| | | | Th-227 (18.72 days) |
| | | | Fr-223 (21.8 minutes) |
| | | | Ra-223 (11.43 days) |
| | | | Rn-219 (3.96 seconds) |
| | | | Po-215 (1.78 milliseconds) |
| | | | Pb-211 (36.1 minutes) |
| | | | At-215 (0.10 milliseconds) |
| | | | Bi-211 (2.14 minutes) |
| | | | Po-211 (0.516 seconds) |
| | | | Tl-207 (4.77 minutes) |
| | | | Pb-207 Stable |

4.1.3 Nuclear Logging of the Waste Zone

Nuclear logging data were gathered to provide information on the physical, chemical, and radiological conditions within the SDA waste zone. Beginning in December 1999, 142 cased steel probeholes were installed in waste-bearing portions of Pits 4, 5, 9, and 10 of the SDA (see Figure 4-2). Type A probes within these probeholes provide the ability to conduct in situ characterization of subsurface soil and waste material by lowering nuclear logging tools into the probehole. The nuclear logging tools measure soil moisture, gamma radiation **flux**, neutron radiation flux, and chemical characteristics within the soil and waste surrounding the probeholes. Table 4-7 gives a brief description of the logging tool suite.

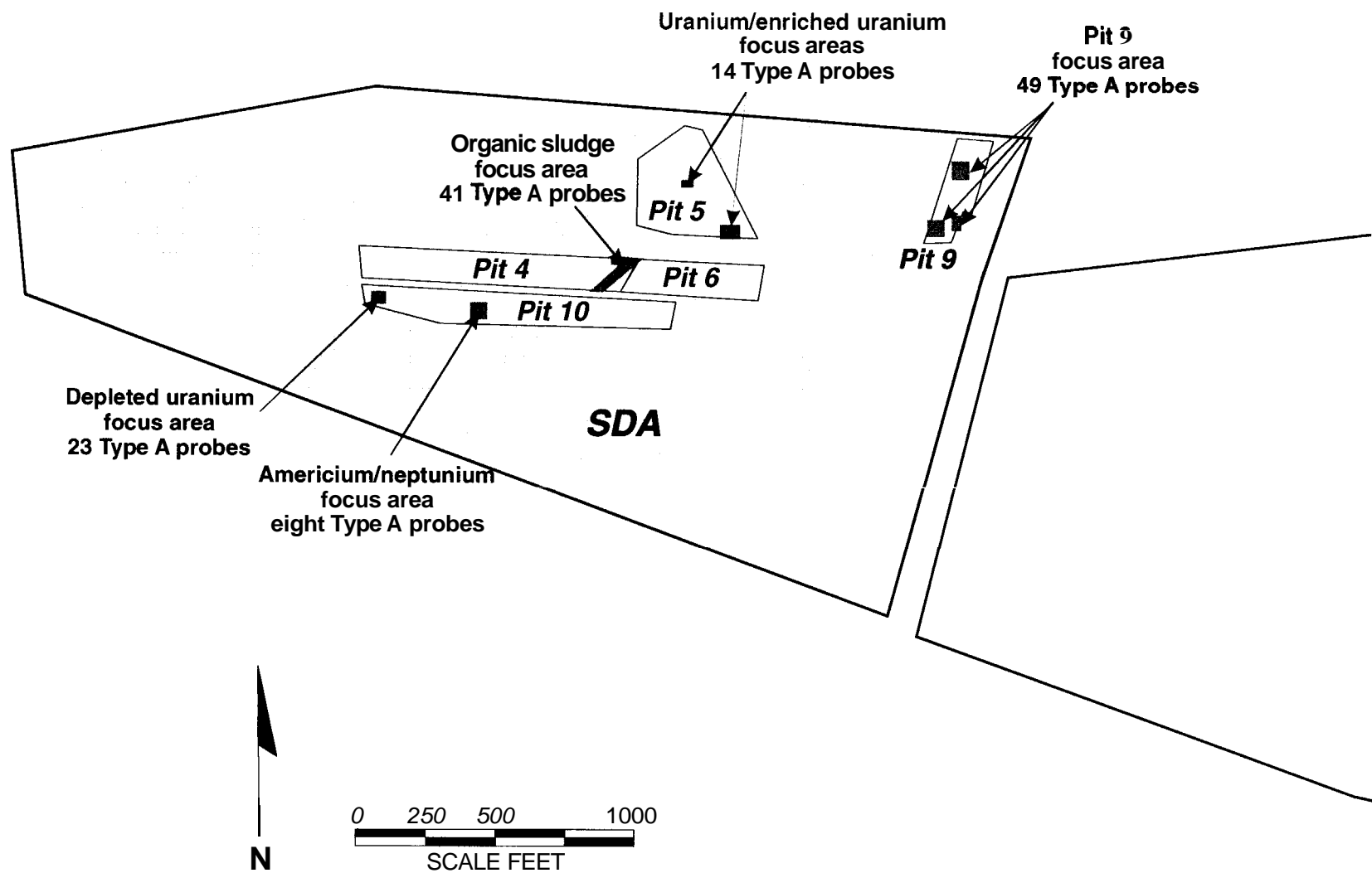


Figure 4-2. Locations of the Type A probes from which nuclear logging data were obtained.

Table 4-7. Description of Type A probe logging tools.

| Tool | Detector Type | Detection Capabilities |
|-------------------------------|--|---|
| Spectral gamma log | Germanium gamma detector. | Gamma-emitting radionuclides. |
| Passive neutron log | He-3 neutron detector. | Fissile radionuclides. |
| Moisture log | Americium/beryllium neutron source combined with neutron detector. | Total hydrogen. |
| Activated gamma (n-gamma) log | Cf-252 neutron source combined with germanium gamma detector. | High neutron capture cross-section elements such as chlorine, iron, silicon, and calcium. |
| Azimuthal spectral gamma log | Germanium gamma detector with slotted shield. | Rotated in probes to determine direction of maximum gamma flux. |

4.2 Surface Sample Data

Samples of the SDA overburden, nearby surface soil, surface water runoff, and vegetation in the RWMC area are classified as surface data. Only the top 6 cm (2 in.) of soil is sampled. Because the SDA has been recontoured with clean soil several times between 1986 and the mid 1990s, comparison of recent surface soil data (1997 to 2000) to data collected before 1997 to assess trends is not meaningful.

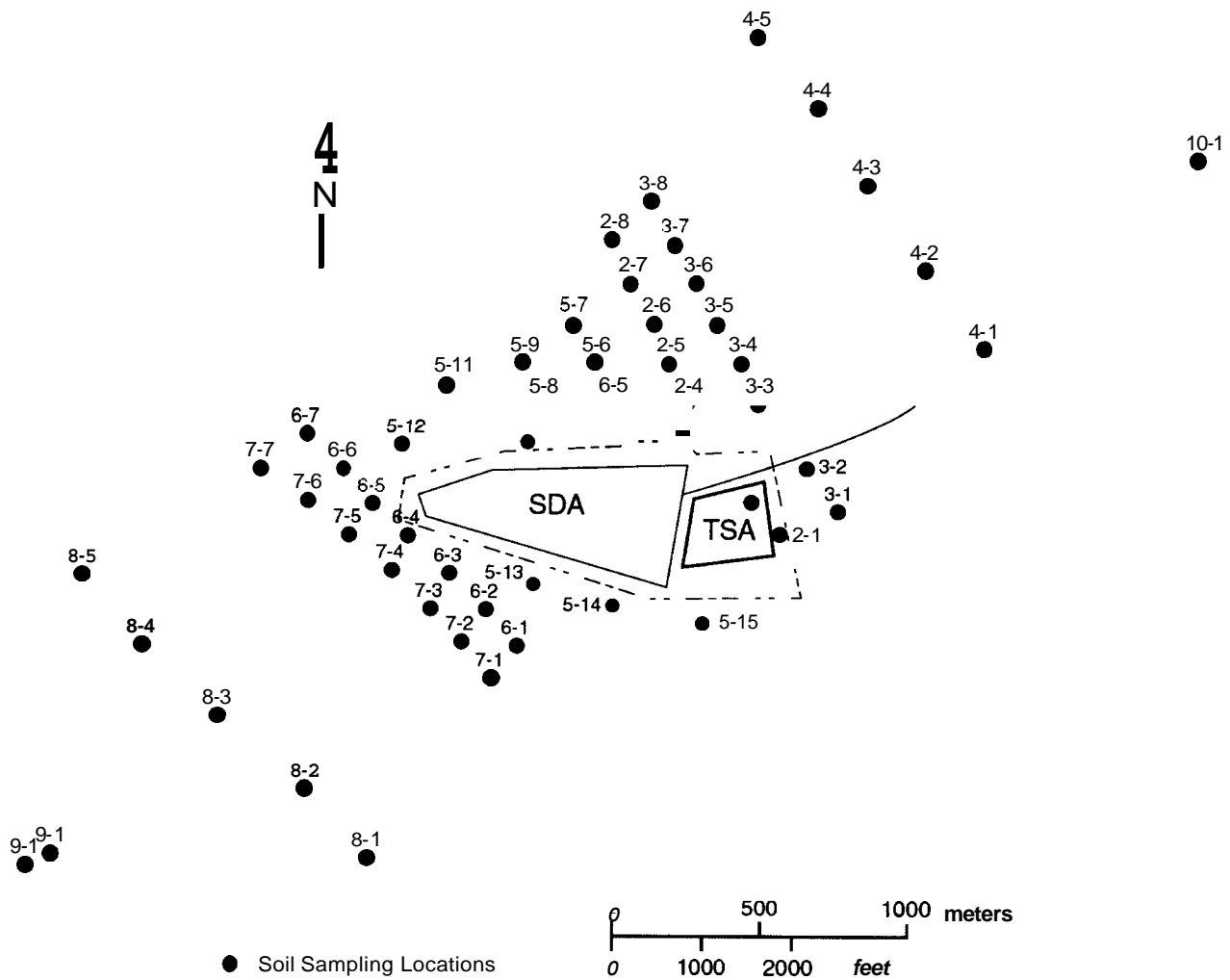
All samples are analyzed by gamma spectroscopy, and selected samples based on activity are analyzed using radiochemistry. Surface soil samples are collected around the RWMC every 3 years and analyzed by gamma spectroscopy for selected radionuclides. The sample locations for the RWMC soil samples are shown in Figure 4-3, with the SDA-specific samples shown in Figure 4-4 and TSA-specific locations shown in Figure 4-5. Vegetation samples are collected in the areas shown in Figure 4-6. Vegetation samples are collected annually, with crested wheatgrass and perennials collected in odd years and Russian thistle collected in even years. Surface water runoff samples, if available, are collected quarterly in the locations shown in Figure 4-7.

4.3 Vadose Zone Data

The vadose zone is defined as the unsaturated interval between the land surface and the aquifer. The primary sources of data used to describe contaminants in the vadose zone were suction lysimeter network samples, perched water samples, and soil and rock core.

4.3.1 Suction Lysimeter Network

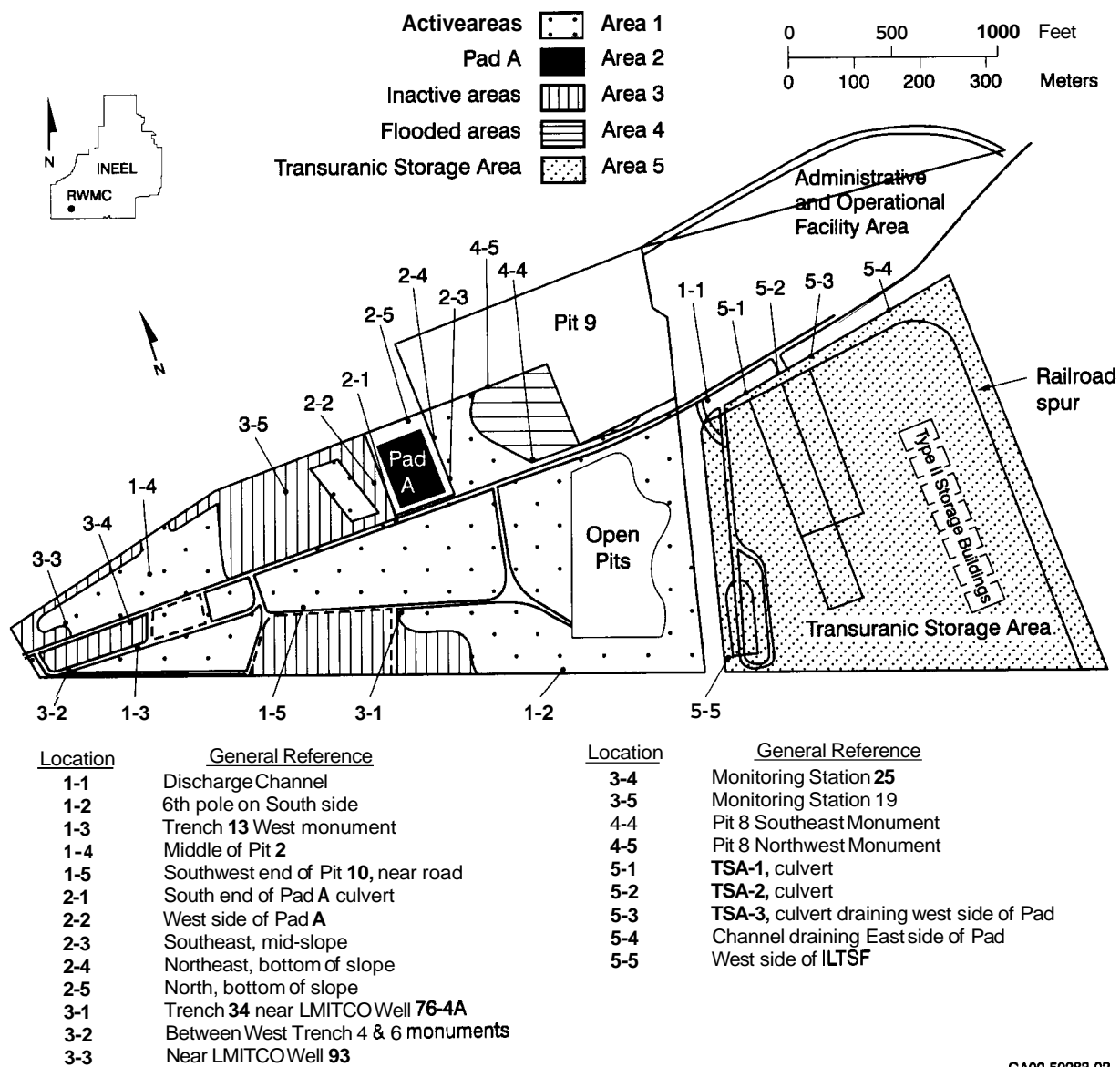
Lysimeter sampling is conducted to characterize the soil moisture (i.e., water that accumulates in soil pores) in the vadose zone. A network of suction lysimeters was installed around the RWMC to allow repeated samples to be collected from the sediments near the buried waste and from the underlying interbeds. Though the first lysimeter samples were collected at the INEEL in 1985 (Hubbell et al. 1985), routine lysimeter sampling did not begin until 1997. The network of lysimeters installed within the vadose zone around the RWMC is shown in Figures 4-8 and 4-9.



GE99 0136

RWMC Soil Sampling Grid

Figure 4-3. Surface soil sampling locations around the Radioactive Waste Management Complex.



GA02-50283-02

Figure 4-4. Surface soil sampling locations at the Subsurface Disposal Area.

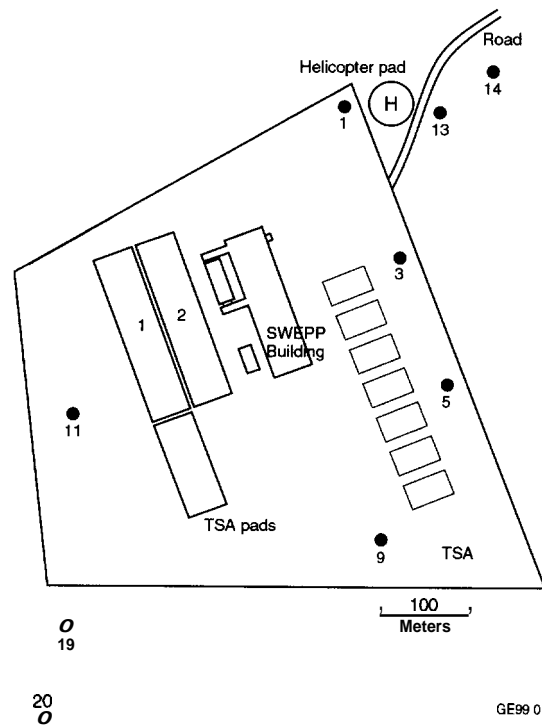


Figure 4-5. Surface soil sampling locations at the Transuranic Storage Area.

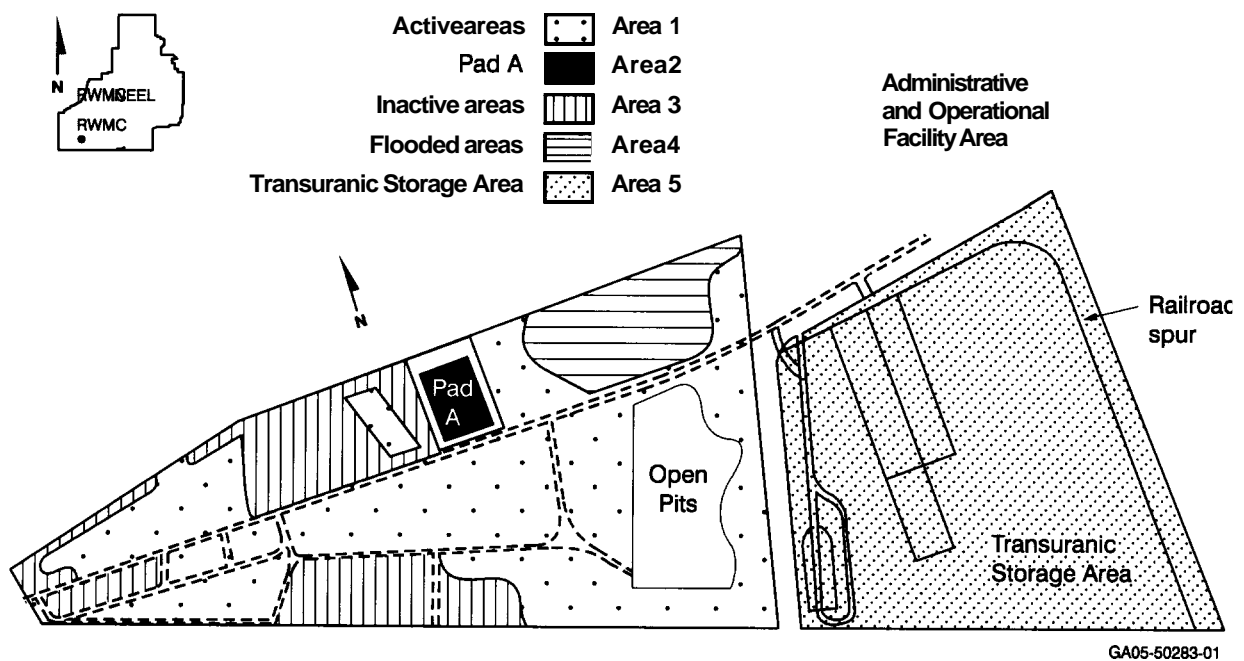


Figure 4-6. Vegetation sampling areas at the Radioactive Waste Management Complex.

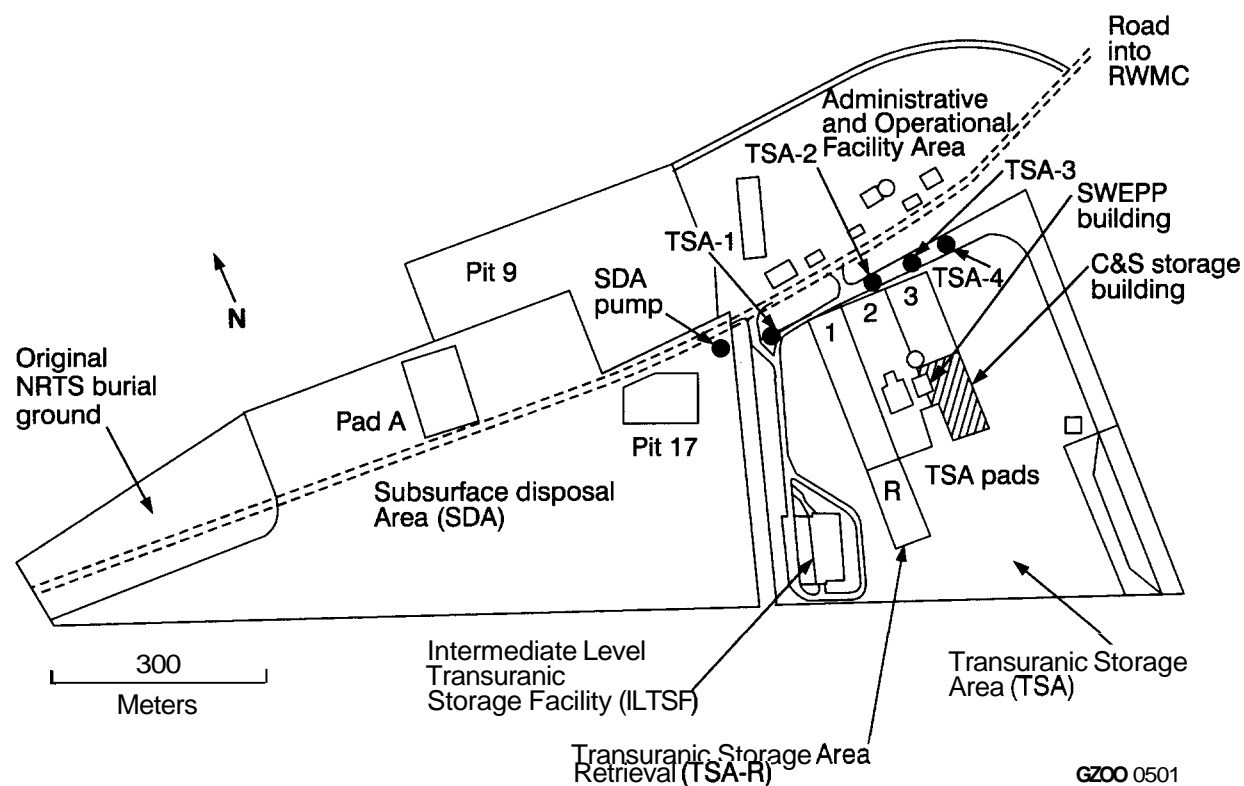


Figure 4-7. Surface water runoff sampling locations at the Radioactive Waste Management Complex.

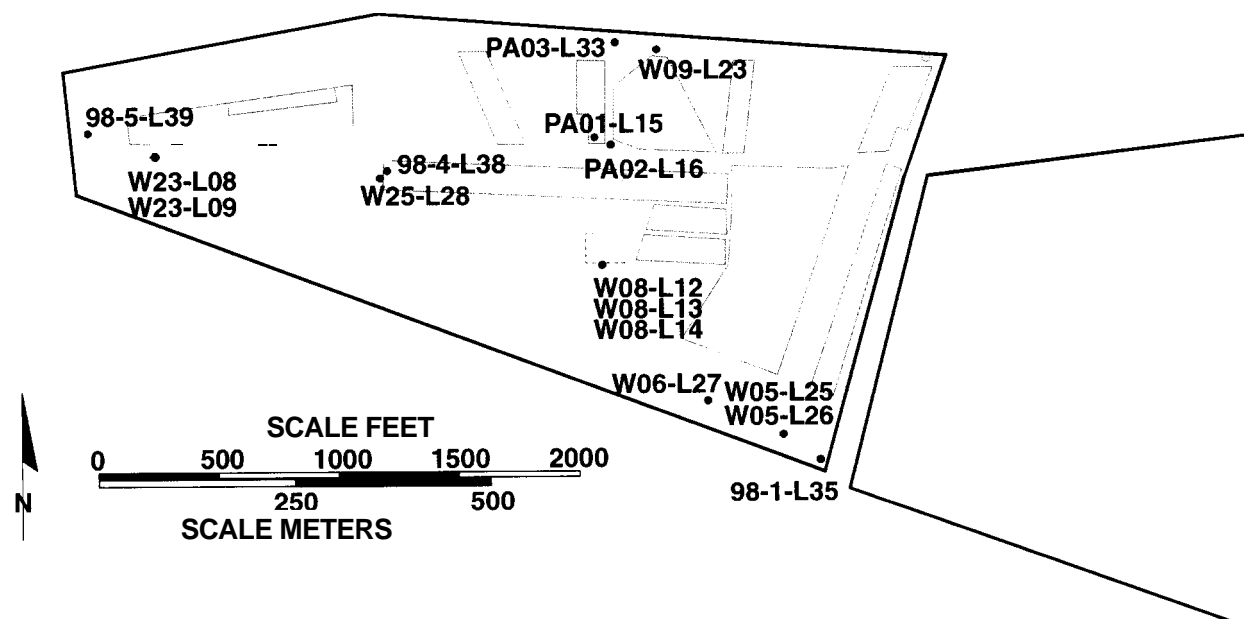


Figure 4-8. Shallow lysimeters located at depths from 0 to 35 ft.

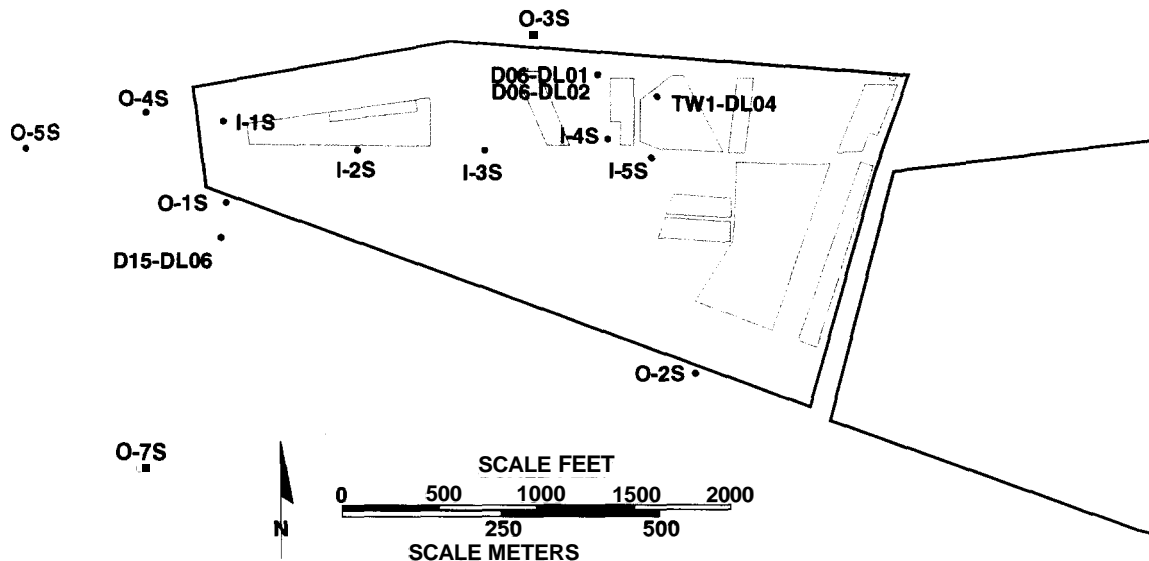


Figure 4-9. Lysimeters located in the intermediate vadose zone at depths ranging from 35 to **140 ft**.

Very small volumes of soil moisture, typically 0 to **200 mL**, are usually obtained from lysimeters, and 50 mL of that total volume is generally allotted for each separate analysis. The detection limits vary with the sample volume available for analysis. Detection limits increase (i.e., are less sensitive) as sample volumes decrease because of the difficulty associated with precision measurement of small amounts of sample matrix. When the soil is relatively dry, a soil moisture sample cannot be collected from the lysimeter. Analyses are prioritized to obtain the most essential data first.

Though risk-based standards and regulatory limits do not apply to the soil moisture data, comparison to such limits provides a frame of reference, particularly for radionuclides that are naturally occurring. Therefore, results from soil moisture analyses are evaluated against one of the parameters listed below:

- Maximum contaminant levels (MCLs) for groundwater
- When MCLs were not available (e.g., Am-241), or were not specific to an isotope (e.g., plutonium and uranium isotopes) data were compared to the aquifer risk-based concentrations (RBCs) equivalent to an increased cancer risk of **1E-05**
- Background concentrations when available.

The soil moisture results are discussed by depth interval as follows:

- Shallow vadose zone with depths ranging from 0 to 35 ft (0 to **10.9 m**) (see Figure 4-8).
- Intermediate interval from 35 to **140 ft (10.9 to 42.7 m)** corresponding roughly to the interval between the A-B and B-C interbeds (see Figure 4-9).
- Deep vadose zone at depths greater than **140 ft (42.7 m)**. The deep vadose zone is sampled by bailers and suction lysimeters at the locations shown in Figure 4-10.

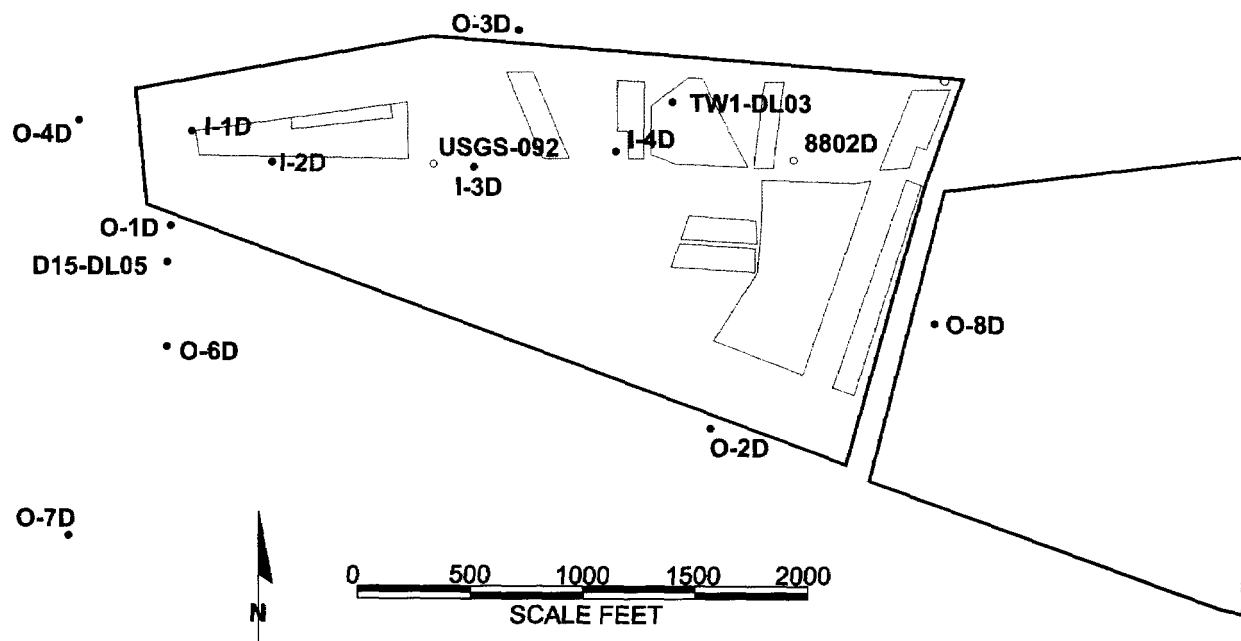


Figure 4-10. Lysimeters and bailers located in the deep vadose zone at depths greater than 140 ft.

4.3.2 Perched Water Sampling with a Bailer

Perched water is present in isolated lenses above the sediments comprising the B-C and C-D interbeds. Samples from the water perched above the C-D interbed are obtained with a bailer from Wells USGS-92 and 8802D. Well USGS-92 was installed in 1972 and Well 8802D in 1988. These perched water wells have slow recharge rates and thin depths of water, often limiting the volume of water sample that can be collected in the bailer. Generally, samples can be collected at Well USGS-92, but success is sporadic at Well 8802D.

4.3.3 Core Sampling

Nine core investigations have been conducted at the RWMC between 1971 and 2000. The investigations were conducted by the USGS (1971 to 1972), the DOE (1975), and various INEEL contractors (1976 to 1977, 1978, 1979, 1986 to 1987, 1993, 1994, and 1999 to 2000). Cores were extracted from numerous locations around the RWMC (see Figure 4-11). Many cores extend to the aquifer, with several depth intervals per core targeted for analyses. Core results are compared with calculated $1\text{E-}05$ RBC for soil.

4.4 Aquifer Data

Most of the aquifer data come from INEEL and USGS sampling around the RWMC. Fifteen aquifer monitoring wells are monitored by the INEEL and eight additional aquifer wells are monitored by the USGS. The locations of the aquifer monitoring wells are shown in Figure 4-12. The INEEL wells around the RWMC were installed between 1992 and 2000. The USGS wells near the RWMC were installed between 1971 and 1987.

Quarterly monitoring is typically planned for the INEEL and USGS wells each year, though sometimes only three rounds of samples are collected from the **RWMC** wells by the INEEL in any given year because of funding constraints. When the INEEL performs its quarterly sampling, the USGS and state oversight program also sample a few specified RWMC wells. Typically, the USGS and state oversight program sample Wells M1S and M3S in conjunction with the INEEL. Recently the USGS began cosampling Wells M7S, M11S, M12S, M13S, and M14S with the INEEL. The USGS shares their analytical data with the INEEL. The state oversight program also shares its analytical data with the INEEL when detections occur. The INEEL does not maintain records of state oversight program analytical data. When detections occur, the INEEL, USGS and state oversight program generally corroborate to confirm detections and to resolve analytical anomalies.

4.5 Data Interpretation Considerations

Accurate interpretation of analytical data requires an understanding of the limitations of analytical methods, such as the impact of sample preparation and potential errors associated with the measurements. Some of the key issues affecting data interpretation for the aquifer monitoring samples are discussed in the following sections.

4.5.1 Quality Assurance

Several quality assurance steps are implemented to ensure that aquifer data are of the highest possible quality and that the reported concentrations are representative of the concentrations in the samples. These steps include the following:

- **Laboratory subcontracting**—Laboratories analyzing INEEL samples undergo a very rigorous evaluation, certification, qualification, and approval process. The laboratory must satisfy the requirements of the national integrated contractor purchasing team and audits by the DOE national environmental monitoring and consolidated auditing program.
- **Intercomparison quality control performance programs**—Subcontracted laboratories are required to routinely participate in national intercomparison program quality control testing. The test results provide an indicator of a laboratory's analytical abilities, performance, and reliability.
- **Performance evaluation samples**—Blind performance evaluation samples are prepared with each quarterly round of aquifer samples by a separate certified and authorized laboratory and submitted to the laboratory analyzing the INEEL aquifer samples. The prepared samples are spiked with known concentrations to assess the accuracy and precision being achieved by the laboratory for routine analytical measurements. If the results do not agree with the known concentrations, all results for the affected analyte are flagged in accordance with data validation procedures as either questionable or rejected.
- **Laboratory control sample**—The laboratory is required to prepare and analyze a laboratory control sample concurrently with each batch of aquifer samples. The control sample is a spike containing known quantities of the analyte of interest prepared by the laboratory, and the control sample is processed with each batch of field samples. This sample provides a means of measuring laboratory performance and the accuracy of the analytical method. The results also are used to indicate whether the laboratory's radiochemical procedure is capable of recovering the contaminant of interest. If the percent recovery for the control samples is unsatisfactory, the rest of the aquifer sample results for the affected analyte are flagged as either questionable or rejected, in accordance with the percent recovery test criterion defined in the data validation procedures.

- **Matrix spikes** — The laboratory is required to prepare a matrix spike and matrix-spike duplicate from an aliquot of an INEEL aquifer sample. The aliquot is spiked by the laboratory with known quantities of pertinent analytes and is processed with each batch of aquifer samples. The results provide information about the effect of the sample matrix on the sample preparation and analytical processes. If the percent recovery for the matrix spike is unsatisfactory, the rest of the results for that particular analyte are flagged as either questionable or rejected, in accordance with data validation procedures.
- **Method blank** — The laboratory is required to run a laboratory-generated blank sample (i.e., method blank) with each round and batch of aquifer samples. This test is used as a means of determining the existence and magnitude of contamination resulting from the sample preparation and analysis process (e.g., from chemical reagents, laboratory glassware, laboratory equipment, or instruments). If the method blank has detectable contamination, the rest of the aquifer sample results for that particular analyte are flagged as either questionable or rejected, with consideration given to the magnitude of the difference between the blank result and the field sample results.
- **Laboratory duplicate** — The laboratory is required to prepare a laboratory-generated duplicate (i.e., split) from one of the INEEL field samples. Duplicate analyses can indicate analytical variability and laboratory precision or the homogeneity of the sample. The duplicate results must satisfy relative percent difference criteria and mean-difference criteria. If the criteria are not satisfied, either the duplicate sample results or the rest of the aquifer sample results for that particular analyte are flagged as either questionable or rejected, in accordance with the mean-difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for that particular matrix.
- **Field duplicate** — A field duplicate is a second sample collected in the field from the same well as each quarterly round of samples. The field duplicate provides information about the representativeness, homogeneity, and variances associated with each field sampling and monitoring event. If the relative percent difference and mean-difference criteria are not satisfied, the rest of the aquifer sample results or only the duplicate sample results (for that particular analyte) are flagged as questionable or rejected, in accordance with the mean difference test criterion defined in data validation procedures, which depends on the sample matrix and known sample homogeneity for the particular matrix.
- **Field blank** — A field blank is a container of clean deionized water that is prepared and collected in the field. The field blank container accompanies the samplers throughout the entire sampling event. At each wellhead, the container is opened, and a small amount of the clean deionized water is poured into the blank container. The field blank is submitted to the laboratory and analyzed with each set of aquifer samples. The field blank provides information that is used to assess whether any sample contamination was introduced by field operations and conditions. **If** the field blank has detectable contamination, the rest of the aquifer samples for the detected contaminant are flagged as questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. The mean difference test criteria are defined in data validation procedures.
- **Performance evaluation blank** — A performance evaluation blank is prepared by a certified and authorized performance evaluation sample laboratory. The blank is sealed at the preparation laboratory and never opened until it is received by the analyzing laboratory for INEEL aquifer samples. The blank provides information that is used to assess whether any sample contamination was introduced at the laboratory. **If** the blank has detectable Contamination, then the rest of the aquifer samples for the detected contaminant are flagged as either questionable or rejected,

depending on the magnitude of the difference between the blank result and the field sample results. The mean-difference test criteria are defined in the data validation procedures.

- **Equipment rinsate** — Water is poured over, around, and through the sampling equipment after use. This sample is analyzed with each set of aquifer samples. It provides information used to assess whether any sample contamination was introduced by the sampling equipment. If the rinsate blank has detectable contamination, the rest of the aquifer samples for the detected contaminant are flagged as either questionable or rejected, depending on the magnitude of the difference between the blank result and the field sample results. The mean difference test criteria are defined in the data validation procedures.
- **Reanalysis** — When an aquifer sample contains a concentration of a radionuclide greater than 2σ (see Section 4.5.2), the laboratory is required to pull another aliquot from the sample container and analyze it. Reanalysis of the same sample can confirm a detection and also can provide information about sample inhomogeneity. Both results are reported. If the reanalysis result is a nondetect, the sample result is not considered a confirmed detection.
- **U.S. Geological Survey sampling** — The USGS routinely collects samples from a subset of wells that are simultaneously sampled by the INEEL. The USGS validates their results and provides them to the INEEL. The two sets are compared to help assess and confirm low-level detections.
- **Laboratory performance evaluation program** — The performance of each subcontracted laboratory using various performance indicators is continually assessed and tracked by the INEEL using a formalized and documented plan (PLN) -491, “Laboratory Performance Evaluation Program Plan, INEEL Sample Management Office.” This program ensures that INEEL project sample analyses are performed by the best performing subcontracted laboratories.

4.5.2 Radiological Uncertainty

When radioactive materials decay, they emit alpha particles, beta particles, or photons (i.e., X-rays and gamma-rays). Emissions from the parent atoms are random and erratic and cannot be precisely measured. If the rate of radioactive decay is fast, then many particles or photons are being emitted and the radioisotope has a short half-life. Conversely, if the emission rate is slow, few particles are emitted and the radioisotope has a long half-life. The lower the emission rate, the longer the half-life and the higher the measurement uncertainty. For environmental level radioactivity, where the emissions typically occur less frequently, a much longer measurement interval is required to obtain an accurate count of the emissions and quantify the amount of radioactivity present.

Radiological uncertainty is a reported value that accompanies the reported concentration, and also follows a known probability distribution. The uncertainty value reported with each measured result is a total of all the recognized errors in the entire analytical process and is referred to as the total propagated uncertainty. The laboratory-reported uncertainty for each sample is given by the statistical standard deviation symbol, the Greek lower-case sigma (σ). All laboratories subcontracted through the INEEL are required to report uncertainties at the 1 σ confidence level. Radioanalytical results are reported as a measured concentration plus or minus its uncertainty. The uncertainty measure is a function of the standard deviation and identifies a range of values that bracket the true sample value with a specified level of confidence. The standard deviation associated with each radioanalytical measurement is a very predictable value because the statistical probabilities associated with the radioactive decay processes are very well understood.

The reported uncertainty value is used to define the confidence interval for the measurement. The confidence interval for a single measured value simply defines where a specified percentage of the data would occur on repeated measurements. The 68.3% confidence interval for a value is formed by plus or minus 1 σ .

Examples for 1 σ , 2 σ , and 3 σ are shown in Table 4-8. For example, a value of 10 with $\sigma = 3$ (i.e., 10 ± 3) indicates that, upon repeated measurements, 68.3% of the results would fall between 7 and 13. Another way of looking at a value of 10 ± 3 is that it specifies with 68.3% certainty that the true value lies somewhere between 7 and 13. Similarly, $\pm 2\sigma$ defines the 95.4% confidence interval, while the 99.7% confidence interval is defined by $\pm 3\sigma$. For the example above, 1 to 19 (i.e., 10 ± 9) is the 99.7% result. The result would be considered a positive detection because the measured value (10) is greater than 30 (9), and the entire confidence interval, 1 to 19, is greater than 0. The second example has a larger uncertainty value of 4, indicating a statistical detection at the 95.4% confidence interval but not a positive detection at the 99.7% confidence interval. The 95.4% confidence interval is greater than 0, but the 99.7% confidence interval is not. Thus, confidence that the value is greater than 0, indicating a positive detection, is low.

Table 4-8. Example of the application of uncertainty measurements to radiological data.

| Measured Value | Uncertainty (1 σ) | Uncertainty Level | Measured Value \pm Uncertainty Range | Confidence Level | Confidence Interval |
|----------------|---------------------------|-------------------|--|------------------|---------------------|
| 10 pCi/L | 3 pCi/L | 1 σ | 10 ± 3 | 68.3% | 7 to 13 pCi/L |
| | | 2 σ | 10 ± 6 | 95.4% | 4 to 16 pCi/L |
| | | 3 σ | 10 ± 9 | 99.7% | 1 to 19 pCi/L |
| 10 pCi/L | 4 pCi/L | 1 σ | 10 ± 4 | 68.3% | 6 to 14 pCi/L |
| | | 2 σ | 10 ± 8 | 95.4% | 2 to 18 pCi/L |
| | | 3 σ | 10 ± 12 | 99.7% | -2 to 22 pCi/L |
| 10 pCi/L | 6 pCi/L | 1 σ | 10 ± 6 | 68.3% | 4 to 16 pCi/L |
| | | 2 σ | 10 ± 12 | 95.4% | -2 to 22 pCi/L |
| | | 3 σ | 10 ± 18 | 99.7% | -8 to 28 pCi/L |

The result from a sample measurement is declared as (a) a nondetection, (b) a statistical detection, or (c) a positive detection, depending on its magnitude relative to its uncertainty. If the measured value is between 20 and 30, it is a statistical detection and qualified with a “J” validation flag to indicate the detections are questionable and should only be used as estimated quantities. If the measured value is greater than the sample-specific minimum detectable activity and is more than three times greater than its uncertainty, it is a positive detection. Otherwise, the result is a nondetection. The data quality associated with statistical detections (i.e., $20 < x \leq 30$) does not satisfy criteria for reportable detections; however, statistical detections are evaluated closely for early indication of developing trends or sudden changes.

One of the misconceptions of confidence level is that it expresses a 68.3%, 95.4%, or 99.7% certainty that the measured value is correct. This is not what confidence level implies. Confidence level only implies that we are 68.3%, 95.4%, or 99.7% certain that the true value lies somewhere between the defined confidence intervals.

The confidence level also defines the percentage of results that are expected to be outside the defined confidence interval. For example, at the **99.7%** confidence level, **0.3%** of the results are expected to fall outside the **30** confidence interval when the measurement is repeated. Therefore, the probability that a positively identified result is actually a false positive result is **0.3%**. The opposite can also occur, where the reported value is not a positive detection at the 99.7% confidence interval, but the probability is **0.3%** that such a result could be incorrect (i.e., false negative).

Before 1998, Technical Procedure (TPR) -80, "Radioanalytical Data Validation," defined a radionuclide detection as a result that was greater than the sample-specific minimum detectable activity (MDA) and greater than **20**. After a comparison was made to the detection standards used by other agencies (i.e., **USGS**, **IDEQ**, and the **INEEL Oversight Program**), the detection criteria were changed to greater than the minimum detectable activity and greater than **30** to be consistent with the results reported by other agencies. All results identified as positive detections in this ABRA were assessed with the **30** criterion.

The MDA is defined as the minimum amount of radioactivity in a sample that can be detected with confidence given a defined set of background, sample, instrument, analytical and measurement conditions. The MDA is a probabilistic approach to determine whether radioactive material is present in a sample. The MDA is derived from the sample measurement, and represents the 95% probability that radioactivity is present in a sample. The MDA is defined as $2.71 + 4.65 (B)$, where **B** is the instrument/ambient background, and **2.71** and **4.65** are probabilistic based values. This equation was derived by Currie (1968), and is a standard method for computing the MDA throughout the analytical industry. All laboratories subcontracted through the INEEL Sample Management Office use this method of computing the MDA.

Beginning in **2002**, statistical hypothesis testing to compare sample results to background levels is a planned addition to the radioanalytical data validation process. The hypothesis testing will provide additional information for determining the presence or absence of radioactivity in aquifer samples and will expedite early identification of significant changes or potential developing trends.

4.5.3 Nitrogen Species

Nitrogen is a redox element, and its chemical form in the environment is dependent on the presence or absence of electrons. In reducing environments (e.g., swamps), nitrite (NO_2^-) is most common, and nitrate (NO_3^-) prevails in oxidized environments. Although nitrite might be present in notable quantities in some waste environments, nitrate is the predominant species in INEEL soil, soil moisture, and aquifer samples.

Nitrogen analyses are generally accomplished by ion chromatography (EPA Method **9056**), colorimetry (EPA Method **353.1** or **353.2**), or spectrophotometry (EPA Method **353.3** or **354.1**). When samples are analyzed by ion chromatography, nitrite and nitrate species are individually quantified. When samples are analyzed by spectrophotometry or colorimetry, the samples are generally treated with a reducing agent (e.g., cadmium or hydrazine) to reduce nitrate to nitrite, and the analysis is run on the nitrite. If requested, the laboratory will run a nitrite analysis before reducing the nitrate, then quantify the nitrate species by subtraction, but generally the combined nitrate/nitrite results are reported.

Historically, nitrogen reporting requirements for the INEEL-contracted analytic laboratories were project-specific. Generally, the laboratory reported the combined nitrite/nitrate results as nitrogen, which were input into the Environmental Restoration Information System (ERIS) database as it appeared on the laboratory forms. Sometimes, in cases where it was unclear what the species were, the result may have

been assigned one or more nitrogen codes in ERIS. For example, a sample with **4.2 µg/L** nitrate result may have been archived as **4.2 µg/L** nitrate, **4.2 µg/L** ammonia, and **4.2 µg/L** total nitrogen.

All the nitrogen data used for this report were reviewed against the original supporting documentation (e.g., laboratory reports), and only the nitrogen species reported by the laboratories are presented in the tables. However, it is unclear if the results have been converted to total nitrogen or are reported as nitrogen species in ERIS.

The consequences of this issue on the risk assessment are insignificant. Nitrate is ubiquitous in the environment, and reliable background concentrations have not been established. Therefore, discriminating the possible contribution from the SDA from other sources (e.g., fertilizer) would be problematic even if RWMC monitoring data were more certain. In addition, the quantities of nitrogen-bearing compounds in the buried waste were converted as described in Section 5 for modeling and risk assessment. The concentrations detected in the environment were not used to assess risk.

4.5.4 Nuclear Logging Data

Waste zone data are being collected from a network of probeholes in selected locations throughout the SDA. The probeholes are equipped with up to five different detectors shown in Table 4-7. The spectral gamma and neutron-neutron moisture logging tools were calibrated for a set of standard conditions corresponding to soil having a moisture content, bulk density, average atomic number, and average mass number similar to typical SDA soil (Beitel et al. **2000**; Josten and Okeson **2000**). The results are based on an assumed homogenized, large volume sample (approximately 10 to 15 L [2.6 to 3.9 gal]) and are representative to the extent that the probehole environment meets these conditions. If it is confirmed that these conditions are met, then these tools will be able to provide a quantitative estimate of soil moisture content and radionuclide concentration to assess source term estimates and support remedial design for the SDA. The passive neutron, n-gamma, and azimuthal tools were not quantitatively calibrated and provided only a relative measure of the targeted subsurface characteristics.

For all the tools, measurements are influenced not only by the amount of the contaminant of interest but also by the uniformity of the distributions of the contaminant, the soil, and other waste in the vicinity of the probehole. Therefore, interpretation of the logging response is subject to uncertainty, because the medium characteristics are typically heterogeneous. Nonetheless, the logging data reveal useful information that inventory records cannot provide about the physical, chemical, and radiological conditions at specific locations.

4.5.5 Early 1970s Data

In the early **1970s**, the Atomic Energy Commission sponsored a hydrogeologic study of the RWMC area to determine whether waste buried in the SDA threatened the quality of the SRPA. The objectives of the study were to (a) evaluate the geologic, hydrologic, and geochemical variables that control the potential for subsurface migration of radionuclides from burial trenches to the water table, (b) determine the amount and reach of past radionuclide migration, and (c) construct wells to monitor the groundwater in the SRPA in the vicinity of the burial ground (Barracough et al. **1976**). The study incorporated sampling of sediments, cores, and water.

Core data from this study contained numerous inexplicable detections, which have not been corroborated by subsequent sampling events nearby. Barracough et al. (**1976**) discuss the perplexity of the data, and identify the potential for “artificial contamination” at the borehole or elsewhere. The report indicates a “possibility that artificial contamination, analytical error, and statistical error are responsible

for some of the positive results. However, there are no apparent artificial contamination mechanisms that could reasonably account for all the observed values.” The report also indicates that the detection of multiple contaminants in a single sample discounts the likelihood that the detections were attributable to analytical or statistical error, and stressed that the contaminant levels measured were too high to be artificial contamination.

Most perplexing was that some of the exterior borehole samples unexpectedly contained elevated Cs-137 and Sr-90, as well as detectable plutonium. The authors indicated that a portion of the detected concentrations might have been artificially introduced by the drilling method used (cable-tool method, discussed below). However, the authors also indicated that it was unlikely that the detected contamination could have been accounted for solely by the contamination introduced by drilling or sampling methods, citing that a substantial amount of contamination down hole would have been required to attain the concentrations that were actually measured. Barraclough et al. (1976) state that for the Well 93 air-blown samples from 97 to 105 ft, the 50 pounds of sediment blown up through the annular well space would have to be mixed with at least 5 lb of soil with a Pu-239/240 concentration of 2.4 pCi/g, or 0.5 lb soil with Pu-239/240 concentrations of 24.0 pCi/g, to acquire the average contaminant levels measured (0.24 pCi/g). It is also unlikely that the contamination is real, because there is no plausible source of such levels of contamination in the immediate vicinity.

A fraction of the measured contamination could have been attributable to artificial contamination introduced by the sampling method, samplers, or surface contamination blown into the hole. The four boreholes drilled outside the SDA (USGS-87, -88, -89, and -90) were drilled using the cable-tool method. The cable-tool method is a percussion technique where a heavy bit of hard steel is suspended on a cable and rhythmically raised a few feet and dropped on the formation at the bottom of the borehole. Repeated hammering breaks up the formation. Usually, a couple feet of water is maintained in the bottom of the borehole to cool the bit. Every several feet the tool is retracted to the surface and a bailing tool (hollow cylinder) is lowered to the bottom of the hole on a cable. The bailer is surged up and down in the slurry (water and cuttings) at the bottom of the hole, and a trap door valve on the bottom of the bailer allows the water and suspended rock cuttings to enter. The cuttings are removed from the hole by bringing the bailer to the surface and dumping the contents. Sediment core samples with a 4 in. diameter were obtained with a split spoon, drive core sampling tool. The sediment samples may have contained drilling water. Basalt samples or drill cuttings were a composite mixture of basalt cuttings, drilling water, sediments, and possibly caved material from higher levels within the well (Barraclough et al. 1976). Each of these exterior wells took four to five months of drilling time, with frequent movement of drilling tools in and out of the boreholes. Surface contamination and fallout particles were probably introduced to subsurface samples using this method.

Six boreholes inside the SDA (USGS-91 through USGS-96) were drilled with the dry air rotary drill, which did not require water to cool the bit and probably introduced less contamination than the cable tool method. Samples were collected using a variety of techniques (e.g., Shelby, sediment sampler, air blown) depending on the circumstances. The air-rotary method cuts the borehole by means of rotating a bit, which is pressed against the formation at the bottom of the hole. During drilling, the bit requires cooling and the cuttings must be removed from the hole. Both are accomplished by pumping compressed filtered air down the inside of the drill rod, out and around the bottom of the turning bit, and back up along the annular space between the rod and the borehole wall. Artificial contamination from this method was probably less than that from the cable-tool method; however, surface contamination could be introduced to subsurface samples by contaminating the drill, particles falling into the hole, or during air-blown sample collection at the wellhead.

Despite the possibilities of artificial contamination, Barraclough et al. (1976) indicated that these explanations were not adequate to account for the levels of contamination reported in the samples.

Barracough et al. (1976) state "...there simply is no credible source for those quantities of contamination to make contact and blend with the samples". Such statements point to the possibility of laboratory errors or uncertainties, but adequate quality assurance data (e.g., blanks and spikes) are not available to evaluate this vector. The radionuclide data from 1971 and 1972 provide evidence of contaminant transport to the interbeds, especially in the older parts of the SDA; however, the data from that time period remain questionable (see also DOE-ID 1983; Burgus and Maestas 1976).

As summarized by Barracough et al. (1976), data are questionable because of conflicting evidence. Data collected in the 30 years following the early 1970s do not support the concept of widespread contamination within and outside of the SDA in the vadose zone. Contamination could have been introduced to the subsurface prior to sampling by the water used in the cable-tool drilling process, by windblown or upper borehole sediments falling into the hole, with any of these possibilities exacerbated by the multiple trips up and down the hole to ream the hole and install casing. In addition, statistical (counting) error could account for some of the radionuclide concentrations.

The questionable data include the perched water and aquifer samples collected after the wells were completed. In particular, the aquifer samples from USGS-87 through -90 are questionable because these wells were drilled with the cable-tool method and sampled with a thief sampler. Barracough et al. (1976) state that there was opportunity for contaminated surficial sediments to enter the four exterior wells, and the concentration patterns in samples from these four wells suggest that artificial sample contamination occurred. Subsequent samples from these wells through 2000 have only sporadically contained radioactive contaminants above background.

Though some degree of uncertainty will always be associated with the issue of sample contamination during well drilling, improved techniques were applied to prevent sample contamination in each subsequent well drilling activity. In 1978, the sampling procedure was changed to include split samples that were analyzed independently of one another (Dames & Moore 1994). Protocol required that positive results had to be obtained in both samples (i.e., splits) to confirm the presence of radionuclides. In the 1970s, results were considered positive if they exceeded the 20 (95.4%) confidence interval (Dames & Moore 1994). In addition, the criteria for reporting positive detections have also tightened. In the 1980s, a 30 (99.7%) detection criterion replaced the 20 used previously; however, some data interpreters continued to report 20 results as positive detections. Thus, positive detections were defined with inconsistent protocol. In 1998, the radioanalytical data validation protocol officially adopted and implemented the 30 confidence interval to define a positive detection (see Section 4.5.2). This criterion was consistent with that applied by the USGS, IDEQ, and the INEEL Oversight Program.

Dames & Moore (1994) compiled and statistically reanalyzed most of the subsurface drilling and coring investigation data collected between 1971 and 1987. The core data presented in this report include data from sampling campaigns from 1971 to 2000. The 1993 investigation involved the sampling and analysis of previously unsampled, stored cores to obtain additional subsurface information.

4.5.6 Lysimeter Data

Lysimeters are used to obtain samples of soil moisture from unsaturated sediments or rock. The sample is drawn through a porous membrane or cup on the end of the lysimeter, which is usually imbedded in a silica flour backfill within the vadose zone material. Organic compounds generally are lost during the lysimeter sampling process (Wood et al. 1981). Early researchers noted that a ceramic membrane could interact and influence the chemistry of the material being sampled. Studies of soil water containing common anions, cations, and nutrients demonstrated that the porous membranes could modify the geochemistry of fluids by either sorbing or adding ions (Haines, Wade, and Topp 1982; Lord and

Shepherd 1993). Typically, the chemistry is affected by sorption of ions on the membrane, but several investigations have noted the addition of several trace constituents.

Few data relate to sampling for radionuclides with suction lysimeters. A laboratory partitioning study was conducted to evaluate the influence of the silica flour backfill and the porous cup in the suction lysimeters on sorption of selected radionuclides (Fjeld, Coates, and Elzerman 2000). The study suggests that Sr-85 and U-233 are not significantly attenuated; while Am-241 and **Pu-239(IV)** are attenuated by contact with the silica flour used to backfill the instruments. Tests were conducted on the sorption of radionuclides contained in a simulated groundwater while being passed through the ceramic porous membrane of a suction lysimeter. After **5** hours of contact with the porous cup, approximately 99.9% of the americium, 89% of the plutonium, 33% of the neptunium, and 3% of the uranium was retained in the ceramic. These data indicate the soil moisture collected in porous ceramic suction lysimeters will have lower concentrations of some radionuclides than the soil moisture in the surrounding undisturbed geologic media within the first five hours of sampling. Most of the lysimeters installed before 1999 had the porous ceramic cup.

Suction lysimeters with porous stainless steel were installed in the B-C and C-D interbeds in 1999 and 2000. The stainless steel should be less reactive than the ceramic membranes but may contribute trace metals to the samples.

4.5.7 Aquifer Data

The analysis of water samples collected from the deep wells outside the SDA in 1971 to 1974 showed trace quantities of waste radionuclides in some samples from all four wells. According to the authors of the report containing these data, "...the drilling and well construction techniques, the water-sample-collection methods, and the uniform distribution of positive results in all four wells suggest artificial contamination. Though these data could be the result of some waste migration to the aquifer, they are considered inconclusive evidence at this time" (Barraclough et al. 1976). The data uncertainties introduced by drilling and well construction techniques are described in Section 4.5.6. For water sampling, the static thief sampler is implicated in Barraclough et al. (1976) as causing some of the sample contamination, however, further explanation is not offered.

Samples from USGS-88 in the 1971 to 1972 contained anomalous concentrations of dissolved solids, magnesium, hydroxide, and high pH, suggesting cement contamination in the well. In addition, significant radionuclides were detected in samples from **USGS-89** and USGS-90, which were not confirmed by later sampling, pointing to artificial contamination in these samples. Barraclough et al. (1976) deemed that the data from the 1971 to 1974 sampling events were unreliable. Dedicated submersible pumps were installed in USGS-87, -88, -89, and -90 in October 1974, and sampling methods were developed that included purging three well volumes from the wells before collecting the sample. After implementation of these changes, radionuclides in the wells outside the SDA were not detected.

4.6 Radiological Results

The radionuclide COPCs, tritium (H-3), and additional isotopes of plutonium are discussed in this section. Each radioisotope is evaluated for the waste zone, the surface, the vadose zone media (i.e., soil and rock in core collected during well drilling, soil moisture, and perched water), and the aquifer. Positive detections in the environment are evaluated against comparison concentrations such as **RBC** and **MCLs**. Details of the interpretation of radiological uncertainty associated with radiological results are provided in Section 4.5.2.

4.6.1 Actinium-227

Actinium-227 exists in nature in very small concentrations from the decay of naturally-occurring U-235, and is an anthropic radioisotope that is a decay product of Pu-239. Actinium-227 decays by the emission of alpha and beta particles, has a 21.77-year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Though not typically analyzed for, the presence of Ac-227 can be inferred by the presence of its gamma-emitting progeny (i.e., Th-227) in routine gamma-spectrometric analysis. The results would be reported if it were present at concentrations above the gamma-spectrometric analysis detection limit, which is approximately 10pCi/L. The comparison concentrations for Ac-227 are presented in Table 4-9.

Table 4-9. Comparison concentrations for actinium-227 in soil and groundwater.

| Surface Soil Background Concentration (pCi/g) | Risk-Based Soil Concentration ^a (pCi/g) | Aquifer Background Concentration | Maximum Contaminant Level (pCi/L) | Risk-Based Aquifer Concentration ^a (pCi/L) |
|---|--|--|--|--|
| Not established | 6.8 | Not established | 15 (total alpha) | 0.98 |
| a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05. | | | | |

4.6.1.1 Waste Zone. Approximately 5.12E-07 Ci of Ac-227 were originally disposed of in the SDA. The waste streams containing Ac-227 at the time of disposal are identified in Table 4-10.

Table 4-10. Actinium-227 waste streams and parent isotopes.

| Waste Stream Code or Generator | Waste Stream Description | Activity (Ci) | Proportion of Total |
|--------------------------------------|---|------------------|------------------------|
| CFA-690-1 | Combustibles, animal carcasses, scrap metal, sources, sand, and gravel. | 2.43E-07 | 47.5 |
| TRA | Beryllium blocks. | 1.76E-07 | 34.3 |
| CFA-RWM-1 | Central Facilities Area Sewage Treatment Plant unpainted concrete rubble, drying beds soils, clarifier piping, and trickle filter bricks. | 7.20E-08 | 14.1 |
| D&D-ARA-1 | Low-level waste from the decontamination and demolition of the Auxiliary Reactor Area facilities. Waste stream consists primarily of contaminated metal and debris. | 1.82E-08 | 3.6 |
| Miscellaneous | Miscellaneous minor streams. | 2.86E-09 | 0.6 |
| Total Disposals | | 5.12E-07 | 100 |
| U-235 ingrowth | Half-life equals 7.04E+08 years. See Section 4.6.19 | 1.79E+08 | NA |
| Pu-239 ingrowth | Half-life equals 2.41E+04 years. See Section 4.6.13 | 7.17E+07 | NA |
| Am-243 ingrowth | Half-life equals 7.38E+03 years. See Section 4.6.3 | 4.55E+04 | NA |

Additional quantities of Ac-227 are being generated over time through ingrowth (see Section 4.1.2). Table 4-6 also includes the amount of Ac-227 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, substantial ingrowth requires many thousands of years. However, for completeness, the waste streams that contain parent nuclides also are listed in Table 4-6. Percentages of the total Ac-227 from parent isotopes are not given because the amount of Ac-227 present is dependant on the timeframe assessed.

Spectral gamma logging in the SDA provides no information about the distribution of Ac 227 in the waste zone. Distributions of parent nuclides are discussed in their respective subsections indicated in Table 4-6.

4.6.7.2 Surface. Actinium-227 has not been measured in routine surface sampling.

4.6.1.3 Vadose Zone. No data for Ac-227 are available from vadose zone core samples or from lysimeters. Though samples were not analyzed specifically for Ac-227, its presence can be inferred by concentrations of its Th-227 progeny. Routine gamma spectrometric analysis did not detect Th-227 above the minimum detectable activity.

4.6.1.4 Aquifer. Actinium-227 has not been detected in the aquifer. Though aquifer samples were not analyzed specifically for Ac-227, its presence can be inferred by concentrations of its Th-227 progeny. Routine gamma spectrometric analysis did not detect Th-227 above the minimum detectable activity.

4.6.2 Americium-241

Americium-241 is an anthropic, transuranic radioisotope that is a decay product of Pu-241. It decays by the emission of alpha particles, has a 432.7-year half-life, and was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Because Am-241 is a surface pathway COPC, surface data are most significant to the Am-241 discussion. Americium-bearing waste in the SDA and the available Am-241 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-11.

Table 4-11. Comparison concentrations for americium-241 in soil and the aquifer.

| Surface Soil Background Concentration ^a (pCi/g) | Risk-Based Soil Concentration ^b (pCi/g) | Aquifer Background Concentration | Maximum Contaminant Level (pCi/L) | Risk-Based Aquifer Concentration ^a (pCi/L) |
|--|--|--|--|--|
| 0.011 | 36.6 | Not established | 15 (total alpha) | 4.6 |
| a. Upper 95% tolerance limit with 95% confidence for composited surface soil (Rood, Harris, and White 1996). | | | | |
| b. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05. | | | | |

4.6.2.1 Waste Zone. Approximately 1.83E+05 Ci of Am-241 were disposed of in the SDA, with the majority being disposed of between the years of 1960 and 1972. The waste streams containing the majority of Am-241 activity are identified in Table 4-12.

Table 4-12. Waste streams containing americium-241.

| Waste Stream Code or Generator | Waste Stream Description | Activity (Ci) | Proportion of Total Activity |
|-----------------------------------|--|------------------|------------------------------------|
| RFO-DOW-3H | Uncemented sludge. | 1.46E+05 | 80.0 |
| RFO-DOW-4H | Combustibles — paper, rags, plastic clothing, cardboard, wood and polyethylene bottles (Codes 330,336,337,900, and 970). | 2.52E+04 | 13.8 |
| RFO-DOW-12H | Dirt, concrete, graphite, ash, and soot. | 4.85E+03 | 2.6 |
| INEEL | Idaho National Engineering and Environmental Laboratory reactor operations waste. | 4.01E+03 | 2.2 |
| Miscellaneous | Miscellaneous minor streams. | 2.56E+03 | 1.4 |
| Total Disposals | | 1.83E+05 | 100 |
| Pu-241 ingrowth | Half-life equals 14.4 years. See Section 4.6.13 | 3.25E+04 | NA |

Additional quantities of Am-241 are being generated over time through ingrowth (see Section 4.1.2). Table 4-6 also includes the amount of Am-241 that would be produced by decay of the parent if all of the parent decayed. Because Pu-241 has a short half-life, the contribution to the Am-241 inventory occurs during the time period of evaluation. Percentages of Am-241 from the parent Pu-241 are not given because the amount of Am-241 present is dependent on the timeframe assessed. In addition, Am-241 will decay and produce substantial inventories of the daughter products Np-237, U-233, and Th-229.

The spectral gamma-logging tool detected Am-241 based on the 662 and 722 keV gamma rays. Of the 135 probeholes logged using this tool, 76 (56%) showed the presence of Am-241 above the noise level. Of the 4,863 total measurements (i.e., all probes and all depths), 1,068 (22%) showed the presence of Am-241 above the noise level. The Am-241 detection limit was approximately 35 nCi/g for the 662 keV gamma rays and 65 nCi/g for the 722 keV gamma rays. The maximum and average observed Am-241 levels were 30,449 and 841 nCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Am-241 is uniformly distributed in the vicinity of the measurement points.

4.6.2.2 Surface. A total of 186 soil samples were collected between 1994 and 2000 from in and around the RWMC. Based on gamma spectrometric analytic results, 76 samples were evaluated for Am-241. There were 55 positive detections of Am-241, ranging from $(1.02 \pm 0.34)E-02$ pCi/g at Pad A (LMITCO 1999) to 1.6 ± 0.2 pCi/g at Pad A (LMITCO 1995c).

A total of 124 vegetation samples were collected between 1990 and 2000 from the RWMC and control locations. Of about 30 samples analyzed for Am-241, eight were positive detections ranging from $(1.04 \pm 0.33)E-03$ pCi/g (LMITCO 1998) to $(1.14 \pm 0.20)E-01$ pCi/g (LMITCO 1998).

A total of 210 surface run-off water samples were collected between 1991 and 2000 from the RWMC and control locations. Based on gamma spectrometric analytic results, about 93 samples were evaluated for Am-241, resulting in eight positive detections. The positive results ranged from $(6.62 \pm 1.59)E-02$ pCi/L (LMITCO 1999) to 3.8 ± 0.7 pCi/L (EG&G 1992). All run-off concentrations were less than the aquifer RBC of 4.6 pCi/L used for comparison.

4.6.2.3 Vadose Zone. The distributions of Am-241 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

4.6.2.3.1 Vadose Zone Core Samples—A total of 321 core samples were collected during well drilling and analyzed for Am-241 between 1971 and 2000 with 34 positive detections (see Table 4-13). The number of detections associated with each depth interval is shown in Table 4-14.

Table 4-13. Positive detections of americium-241 in vadose zone core samples.

| Borehole Identification | Sample Depth (ft) | Concentration $\pm 1\sigma$ (pCi/g) | Date |
|-------------------------|-------------------|-------------------------------------|--------------|
| D02 | 1.2 to 1.7 | 1.52 ± 0.06 | 1987 |
| | 15.5 to 16.0 | 0.050 ± 0.005 | 1987 |
| 4E | 10.0 to 22.5 | 9.6 ± 0.7 | 1994 |
| 76-3 | 97.5 to 97.8 | 0.0084 ± 0.0014 | 1976 |
| 76-4A | 23.5 | 0.021 ± 0.003 | 1976 |
| | 97.8 | 0.0064 ± 0.0017 | 1976 |
| | 226.0 | 0.023 ± 0.003 | 1976 |
| 78-2 | 235.7 | 0.033 ± 0.003 | 1978 |
| 79-2 | 99.1 to 99.9 | 0.031 ± 0.003 | 1979 |
| | 99.1 to 99.9 | 0.022 ± 0.002 | 1979 |
| | 99.9 to 101.7 | 0.013 ± 0.003 | 1979 |
| | 99.9 to 101.7 | 0.018 ± 0.002 | 1979 |
| | 101.7 to 103.0 | 0.024 ± 0.003 | 1979 |
| | 101.7 to 103.0 | 0.020 ± 0.003 | 1979 |
| USGS-93 | 13.8 to 14.0 | 0.012 ± 0.003^a | 1972 |
| | 101.0 to 103.0 | 0.063 ± 0.010^a | 1972 |
| | 101.0 to 103.0 | 0.15 ± 0.02^a | 1972 |
| | 103.0 to 105.0 | 0.045 ± 0.004^a | 1972 |
| USGS-96 | 110.0 to 112.9 | 0.030 ± 0.006^a | 1972 |
| TWI | 101.0 to 101.2 | 0.44 ± 0.02 | 1987 |
| | 101.0 to 101.2 | 0.47 ± 0.02 | 1987 |
| | 101.2 | 0.103 ± 0.008 | 1987 |
| | 101.2 | 0.106 ± 0.009 | 1987 |
| | 101.2 | 0.137 ± 0.011 | 1987 |
| | 101.2 | 0.908 ± 0.008 | 1987 |
| | 101.2 | 0.107 ± 0.009 | 1987 |
| | 101.2 | 0.085 ± 0.009 | 1987 |
| I-1S | 105.5 | 0.022 ± 0.006 | 1999 to 2000 |
| | 110.6 to 111.0 | 0.021 ± 0.006 | 1999 to 2000 |
| I-1D | 237.6 to 238.0 | 0.016 ± 0.005 | 1999 to 2000 |
| 1-2s | 99.0 to 100.0 | 0.021 ± 0.006 | 1999 to 2000 |
| | 111.0 | 0.019 ± 0.005 | 1999 to 2000 |
| | 112.5 to 113.0 | 0.031 ± 0.008 | 1999 to 2000 |
| I-4D | 237.5 to 238.0 | 0.021 ± 0.007 | 1999 to 2000 |

a. Data from 1972 through 1974 must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-14. Americium-241 detections in vadose zone core samples from each depth interval.

| Depth Interval (ft) | Number of Detections/ Number of Samples (%) | Concentration Range (pCi/g) | Wells or Boreholes with Detections |
|------------------------|---|-----------------------------------|---------------------------------------|
| 0 to 35 | 5/30 (16.7) | 0.012 to 9.6 | 4E, 76-4A, D02, USGS-93 |
| 35 to 140 | 25/139 (18.0) | 0.006 to 0.908 | 76-3, 76-4A, 79-2, TW1; I-1S, I-2s |
| 140 to 250 | 4/142 (2.8) | 0.016 to 0.033 | 76-4A, 78-2, I-1D, I-4D |
| >250 | 0/10 (0) | Not applicable | Not applicable |

Of the 34 positive detections, 32 exceeded the surface soil background concentration of 0.011 pCi/g (Rood, Harris, and White 1996). Detection rates were similar in the 0 to 35-ft and 35- to 140-ft depth intervals, 16.7 and 18.0%, respectively. The detection rate of 2.8% was considerably lower for samples collected at depths greater than 140 ft. Many of the Am-241 detections (i.e., 21 of 34) were corroborated by detections of other actinides such as h-238 and h-239. None of the four detections in the 140- to 250-ft depth interval were accompanied by detections of other actinides.

Six of the 13 cores with detectable Am-241 were located on the west end of the SDA, and three of the 13 occurred near Pad A and Pit 5. Eight analyses from TW1 at the 101-ft depth detected concentrations of Am-241, which provide confirmation that Am-241 is present at that location and depth. The results from Well 4E at 10 ft deep and from Well D02 at 1.5 ft deep, exceeded the surface soil background concentration but are lower than the calculated 1E-05 RBC for soil of 36.6 pCi/g.

4.6.2.3.2 Lysimeter Samples at Depths of 0 to 35 ft—A total of 106 shallow lysimeter samples were analyzed by INEEL for Am-241 between 1997 and May 2001, with five positive detections (see Table 4-15). The occurrence of the detections relative to other sampling events is shown in Figure 4-13.

Table 4-15. Positive detections of americium-241 in shallow lysimeters in the 0- to 35-ft depth interval.

| Lysimeter | Depth (ft) | Concentration $\pm 1\sigma$ (pCi/L) | Confirmation Flag ^a | Date |
|------------------|---------------|---|-----------------------------------|---------------|
| W23-L09 | 7.7 | 0.8 \pm 0.2 | A | November 1998 |
| PA01-L15 | 14.3 | 9 \pm 2^a | B | April 1998 |
| PA03-L33 | 10 | 4.2 \pm 0.7 | A | February 1998 |
| 98-5L39 (SDA-10) | 10.5 | 0.8 \pm 0.2 | B | December 1998 |
| | | 0.30 \pm 0.09 | B | March 2000 |

^a Confirmation flag:

A = No second sample collected, no reanalysis performed.

B = Reanalysis performed, no confirmation.

Note: Concentration in **red bold** indicates that the value exceeds the 1E-05 aquifer risk-based concentration (4.6 pCi/L), which is not applicable to lysimeter samples but is presented as a basis of comparison.

| | | Lysimeter | | | | | | | | | | | |
|------|---------|---|-------------|-------------|--------------|--------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Year | Quarter | 98-1 L35 | 98-4 L38 | 98-5 L39 | PA01- L15 | PA02- L16 | PA03- L33 | W06- L27 | W08- L13 | W08- L14 | W23- L08 | W23- L09 | W25- L28 |
| 1997 | 1 | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | |
| 1998 | 1 | | | | | | 4.2 | | | | | | |
| | 2 | | | | 9 | | | | | | | | |
| | 3 | | | | | | | | | | | | |
| | 4 | | | 0.8 | | | | | | | | 0.8 | |
| 1999 | 1 | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | |
| 2000 | 1 | | | 0.30 | | | | | | | | | |
| | 2 | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | |
| 2001 | 1 | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | |
| Key | | Analysis was performed for Am-241, but none was detected. | | | | | | | | | | | |
| | | Am-241 was detected (pCi/L). | | | | | | | | | | | |
| | | If more than one positive detection occurred in a well in a single quarter, only the highest concentration is listed. | | | | | | | | | | | |

Figure 4-13. Shallow lysimeter monitoring results for americium-241.

The concentration of 9 ± 2 pCi/L in Lysimeter PA01-L15 is relatively high compared to the positive detections in the other samples. The 9 ± 2 pCi/L were yielded by one of two duplicate samples taken from Lysimeter PA01-L15 on the same day. The other sample did not contain detectable Am-241. In addition, seven other sampling events have been performed in Lysimeter PA01-L15 since April 1998, with no other detections. The detection of 4.16 ± 0.66 pCi/L in Lysimeter PA03-L33 was not confirmed with a reanalysis, and the detection was not followed by any positive detections in subsequent sampling events. At least two subsequent samples have been collected following detections from the other wells through May 2001, with no positive detections. Lysimeters 98-5L39 and W23-L09 are located on the west end of the SDA, and Lysimeter PA03-L33 is located near Pad A.

The low concentrations of Am-241 in the lysimeter samples next to vadose zone core samples with detectable Am-241 may be interpreted as evidence of migration. The relatively high detections of Am-241 around Pad A in Lysimeters PA03-L33 and PA01-L15 are comparable to the $1E-05$ RBC for the aquifer. The sample results may be biased low because of possible Am-241 retention in the porous ceramic cup in the lysimeters (see Section 4.5.6).

4.6.2.3.3 Lysimeter Samples at Depths from 35 to 140 ft—A total of 40 lysimeter samples from 13 locations were analyzed for Am-241 between 1997 and May 2001, with three positive detections as listed in Table 4-16. The occurrence of detections relative to nondetections is shown in Figure 4-14.

Table 4-16. Positive detections of Am-241 in lysimeter samples from 35 to 140 ft.

| Lysimeter | Depth (ft) | Am-241 Concentration \pm 1a | Confirmation | Date |
|-----------|---------------|----------------------------------|-------------------|---------------|
| | | (pCi/L) | Flag ^a | |
| D06-DL01 | 88.0 | 0.8 ± 0.2 | A | December 1998 |
| TW1-DL04 | 102.0 | 1.9 ± 0.5 | A | March 2000 |
| D15-DL06 | 98.0 | 2.4 ± 0.7 | A | April 1998 |

a. Confirmation flag:

A = No second sample collected, no reanalysis performed.

| Year | Quarter | Lysimeters | | | | | | | | | | | | TW1-DL04 |
|------|---------|---|----------|----------|------|------|------|------|------|------|------|------|------|----------|
| | | D06-DL01 | D06-DL02 | D15-DL06 | I-1S | I-2S | I-3S | I-4S | I-5S | O-2S | O-3S | O-4S | O-5S | |
| 1997 | 1 | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | |
| 1998 | 1 | | | | | | | | | | | | | |
| | 2 | | | 2.4 | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | |
| | 4 | 0.8 | | | | | | | | | | | | |
| 1999 | 1 | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | |
| 2000 | 1 | | | | | | | | | | | | | 1.9 |
| | 2 | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | |
| 2001 | 1 | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | |
| Key | | Analysis was performed for Am-241, but none was detected. | | | | | | | | | | | | |
| | | Am-241 was detected (pCi/L). | | | | | | | | | | | | |
| | | If more than one positive detection occurred in a well in a single quarter, only the highest concentration is listed. | | | | | | | | | | | | |

Figure 4-14. Intermediate depth (35 to 140 ft) lysimeter monitoring results for americium-241.

The positive sample results could not be confirmed by reanalysis because of the limited water sample obtained from lysimeters. Subsequent samples collected from these three wells through May 2001 have not yielded positive detection of Am-241. Two of the three detections (i.e., Wells D06 and TW1) occurred in the vicinity of Pad A and Pit 5, and the third (Well D15) is located outside the SDA boundary on the southwest end of the site.

Developing trends in the intermediate-depth lysimeter data are not apparent. All three Am-241 detections over a 4-year period were less than the 1E-05 RBC for the aquifer of 4.6 pCi/L used as a basis of comparison. The porous ceramic cup on the lysimeter may be retaining a fraction of the Am-241 (see Section 4.5.6), thus introducing a low bias to the sample results. Therefore, Am-241 could be present in higher concentrations than measured.

4.6.2.3.4 Lysimeter and Perched Water Samples at Depths Greater than 140ft—

Including USGS analyses, a total of 52 perched water samples, 10 filtered sediment samples, and five deep suction lysimeter samples were analyzed for Am-241 between 1974 and December 2000. Two positive detections of Am-241 occurred, both in Well USGS-92 as shown in Table 4-17. Neither sample exceeded the aquifer 1E-05 RBC of 4.6 pCi/L used for comparison. Well USGS-92 is not near locations where Am-241 was detected in vadose zone core samples or in the other lysimeter samples. The detection rate for the deep lysimeter and perched water samples was 3.8% (i.e., two out of 52 samples).

Table 4-17. Positive detections of americium-241 in deep perched water.

| Well | Depth (ft) | Concentration $\pm 1\sigma$ (pCi/L) | Date |
|---------|------------|-------------------------------------|--------------|
| USGS-92 | 214 | 0.041 \pm 0.012 | October 1976 |
| | | 0.14 \pm 0.04 | October 1992 |

Subsequent water samples collected from Well USGS-92 through December 2000 have not shown Am-241 detections. Perched water samples are filtered because they typically contain sediments. The filtered sediments also were analyzed for Am-241 with no positive detections.

4.6.2.4 Aquifer. A total of 261 aquifer samples from INEEL wells were analyzed for Am-241 between 1992, when aquifer monitoring for Am-241 began, and April 2001 with five positive detections. None of the detections exceeded the calculated aquifer 1E-05 RBC of 4.6 pCi/L, as shown in Table 4-18. The distribution of Am-241 detections in the INEEL aquifer samples is shown in Figure 4-15. Only the October 1997 sample result was confirmed by reanalysis of the original sample. Subsequent samples collected from these wells through April 2001 have not shown positive detections.

Table 4-18. Positive detections of americium-241 in the aquifer.

| Aquifer Well | Concentration $\pm 1\sigma$ (pCi/L) | Confirmation Flag ^a | Date |
|--------------|-------------------------------------|--------------------------------|----------------|
| M11S | 0.026 \pm 0.008 | B | April 1999 |
| M1S | 1.13 \pm 0.13 | D | October 1997 |
| | 1.03 \pm 0.08 | D | October 1997 |
| | 1.97 \pm 0.13 | B | May 1998 |
| M3S | 0.027 \pm 0.008 | B | September 2000 |

a. Confirmation flag:

B = Reanalysis performed, no confirmation.

D = Detection confirmed by reanalysis.

Note: Highlighted values are the original and the confirmatory analyses. Positive detection was confirmed.

In addition to the RWMC monitoring aquifer wells managed and routinely sampled by the INEEL, the USGS manages, controls, and routinely samples eight other aquifer wells in the vicinity of the RWMC (see Section 4.4), and also collects samples from some of the INEEL wells. A total of 489 USGS aquifer well samples in the vicinity of the RWMC were analyzed for Am-241 between 1972 and

October 2000, with 23 detections (see Table 4-19). Results from the USGS and INEEL aquifer sampling from 1992 through 2001 are shown in Figure 4-15. Samples collected by the USGS in Wells M1S and M3S from 1997 through 2000 did not verify the positive detections yielded in the INEEL samples. The USGS does not collect samples from Well M11S.

All but two of the USGS detections occurred between 1972 and 1974, shortly after the wells were drilled and installed (see Figure 4-16). The 1972 and 1974 detections are suspect because of possible contamination problems associated with early well drilling and well construction techniques and the types of sampling methodology employed at that time (Barraclough et al. 1976) (see Section 4.5.5). Subsequent samples collected from the USGS wells from 1975 through 2000 have shown only two positive Am-241 detections, one in 1981 and one in 1982. Numerous sampling events since these detections have not identified Am-241. The concentrations of Am-241 detected are well below the aquifer 1E-05 RBC of 4.6 pCi/L.

Summary of Americium-241. Americium-241 is a COPC because it poses a risk in the 1,000-year simulation period from soil ingestion, inhalation, external exposure, and crop ingestion pathways (Becker et al. 1998). Approximately 1.83E+05 Ci of Am-241 were disposed of in the SDA, with about 80% of that being in the form of uncemented sludge from RFP. Americium-241 has been detected in about 56% of the waste zone probeholes examined with the spectral gamma logging tool, and has been detected in surface soil, vegetation, and run-off samples (see Table 4-20).

Approximately 17 to 18% of the vadose zone core samples collected in the 0- to 35-ft and 35- to 140-ft depth intervals contain detectable amounts of Am-241, compared with approximately 3% in the depth interval from 140 to 250 ft. The Am-241 detection rate in soil moisture samples is less than 8% in all depth intervals, and the Am-241 concentrations in the lysimeter samples may be biased low by Am-241 retention on the ceramic cups in the lysimeters (see Section 4.5.6).

Spatially, there appears to be a cluster of Am-241 detections in both vadose zone core samples and soil moisture samples in the 0- to 35-ft and 35- to 140-ft depth intervals in the region below Pad A and Pit 5 and at the western end of SDA near Pits 1 and 2. However, the detections in soil moisture samples are sporadic and do not exhibit temporal trends. Americium-241 was detected in aquifer samples from Well M1S south of Pits 1 and 2 in 1997 and 1998, and from Wells M3S and M11S, which are both upgradient of the SDA. The distribution of Am-241 detections in the various depth intervals is depicted in Figure 4-17.

The aquifer detection rate is very low at 2%. All detections are less than the aquifer RBC of 4.6 pCi/L with the exception of one USGS sample from the questionable 1972 data set.

Table 4-19. Positive detections of americium-241 in aquifer wells monitored by the U.S. Geological Survey.

| Aquifer Well | Concentration \pm 1a (pCi/L) | Date |
|--------------|---|----------------|
| USGS-87 | 0.040 \pm 0.010. | October 1972 |
| | 0.30 \pm 0.02' | May 1973 |
| | 0.11 \pm 0.02' | August 1973 |
| | 0.13 \pm 0.02 ^a | September 1973 |
| USGS-88 | 0.045 \pm 0.008' | April 1973 |
| | 0.13 \pm 0.02 ^a | May 1973 |
| | 0.07 \pm 0.02' | June 1973 |
| | 0.08 \pm 0.02' | August 1973 |
| | 0.07 \pm 0.02 ^a | September 1973 |
| | 0.020 \pm 0.006 | July 1982 |
| USGS-89 | 5 \pm 1^a | October 1972 |
| | 0.011 \pm 0.002' | June 1973 |
| | 0.07 \pm 0.02' | July 1973 |
| | 0.14 \pm 0.03' | August 1973 |
| | 0.09 \pm 0.02 ^a | September 1973 |
| | 0.11 \pm 0.02 ^a | September 1973 |
| | 0.027 \pm 0.002 ^a | January 1974 |
| | 0.09 \pm 0.02 ^a | December 1974 |
| USGS-90 | 1.5 \pm 0.4 ^a | September 1972 |
| | 0.17 \pm 0.02 ^a | April 1973 |
| | 0.07 \pm 0.02' | July 1973 |
| | 0.13 \pm 0.03 ^a | September 1973 |
| | 0.14 \pm 0.04 | October 1981 |

a. The 1972 to 1974 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Note: Concentration in **red bold** indicates that the value exceeds the 1E-05 aquifer risk-based concentration of 4.6 pCi/L.

| Year | Quarter | USGS-87 | USGS-88 | USGS-89 | USGS-90 | RWMC Prod | USGS-117 | USGS-119 | USGS-120 |
|------|---------|---|---------|---------|------------------|-----------|----------|----------|----------|
| 1972 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | 1.5 ^a | | | | |
| | 4 | 0.040 ^b | | 5 | | | | | |
| 1973 | 1 | | | | | | | | |
| | 2 | 0.3 | 0.13 | 0.011 | 0.17 | | | | |
| | 3 | 0.13 | 0.08 | 0.14 | 0.13 | | | | |
| | 4 | | | | | | | | |
| 1974 | 1 | | | 0.027 | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | 0.09 | | | | | |
| 1975 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1976 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1977 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1978 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1979 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1980 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1981 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | 0.14 | | | | |
| 1982 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | 0.020 | | | | | | |
| | 4 | | | | | | | | |
| 1983 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1984 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1985 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1986 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1987 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1988 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1989 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1990 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| 1991 | 1 | | | | | | | | |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | | | | | | | | |
| Key | | Analysis was performed for Am-241, but none was detected. | | | | | | | |
| | | Am-241 was detected (pCi/L). | | | | | | | |
| | | Note: If more than one detection occurred in a well in a single quarter, only the highest concentration is listed. | | | | | | | |
| | | a. Value reported in Barraclough et al. (1976) is 15±0.04 pCi/L in Table IV and 0.15±0.40 pCi/L in Table A-IX. The laboratory data stored on microfiche at the HDR are illegible, thus the value cannot be confirmed. | | | | | | | |
| | | b. Table A-IX in Barraclough et al. (1976) report this value as 0.05±0.01 pCi/L. Laboratory data on microfiche at the HDR indicate that 0.04 pCi/L is correct. | | | | | | | |

Figure 4-16. Aquifer americium-241 monitoring results from the U.S. Geological Survey, 1972 through 1991.